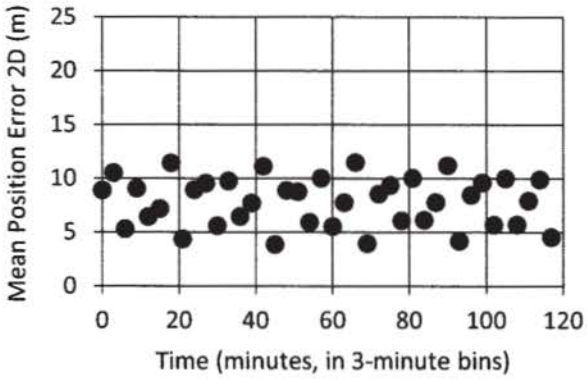
Samsung Tablet

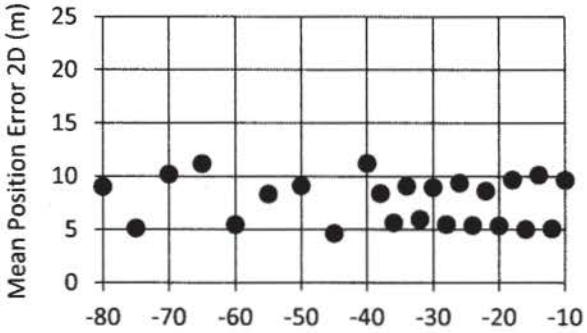
Condition: Open Sky with Motion

1526-1536 MHz Downlink	1627.5-1637.5 MHz Uplink	1646.5-1656.5 MHz Uplink	1670-1680 MHz Downlink
No Impact	No Impact	No Impact	No Impact

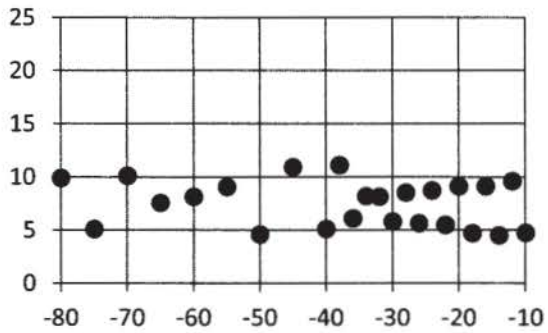
GPS Only (No LTE Signal)



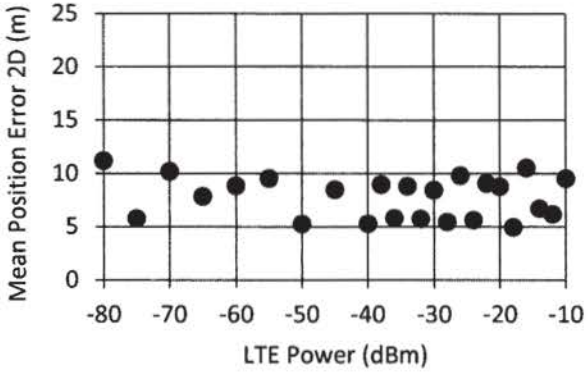
1526-1536 MHz LTE



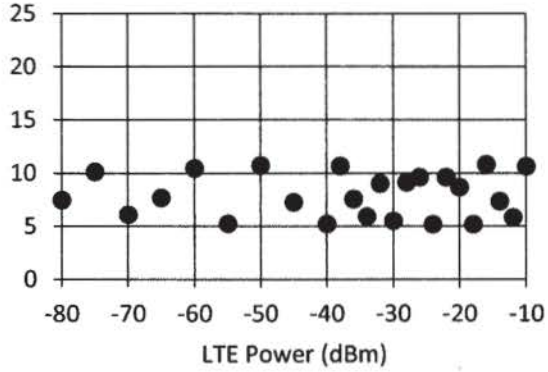
1627.5-1637.5 MHz LTE



1646.5-1656.5 MHz LTE



1670-1680 MHz LTE



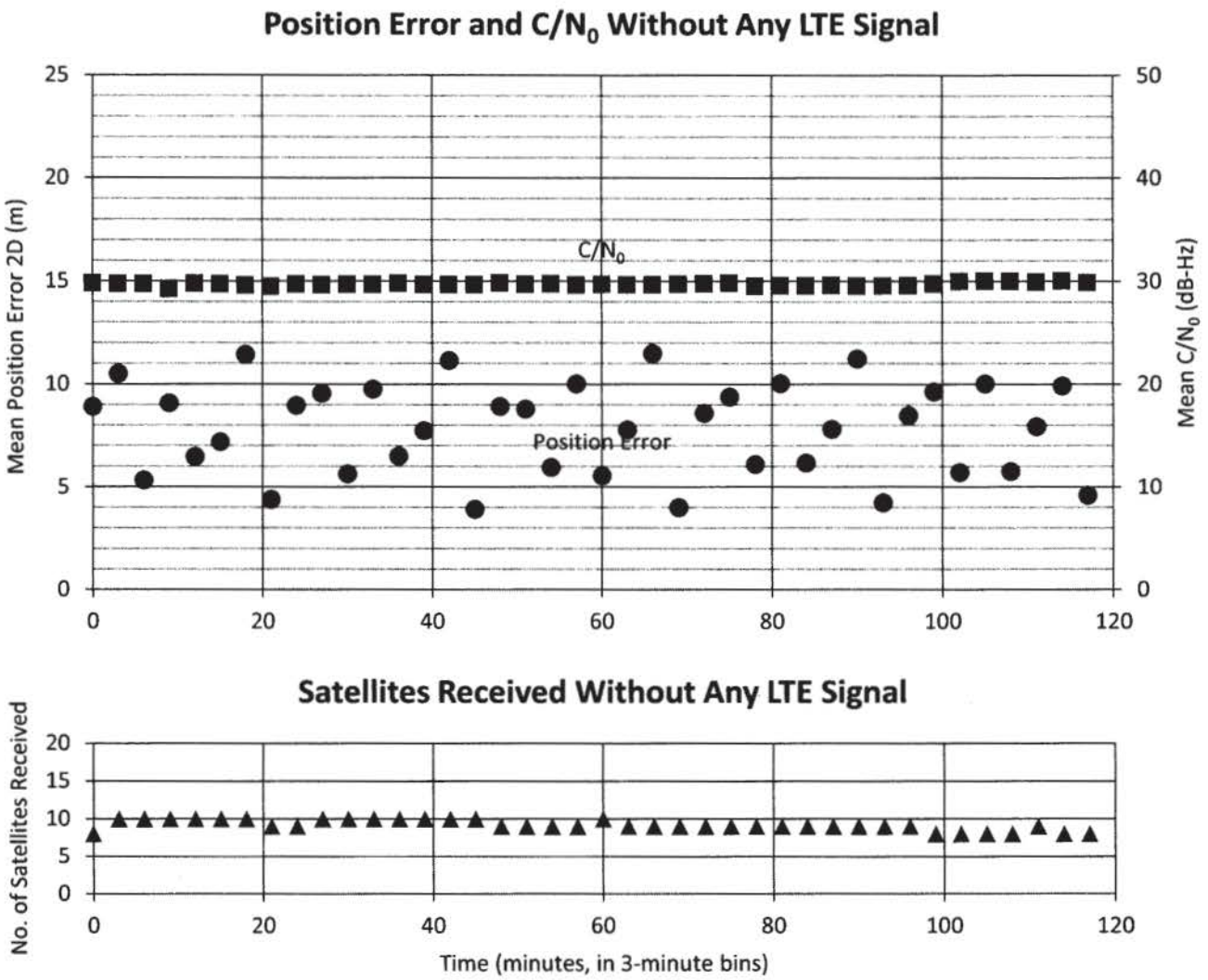
Samsung Tablet
Open Sky with Motion | GPS Only (No LTE Signal)

Device Category: Cellular
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Samsung Tablet
Antenna: Internal

GPS Condition:
Open Sky with Motion

LTE Condition:
GPS Only (No LTE Signal)



● Mean Position Error 2D (m)

■ Mean C/No (dB-Hz)

▲ No. of Satellites Received

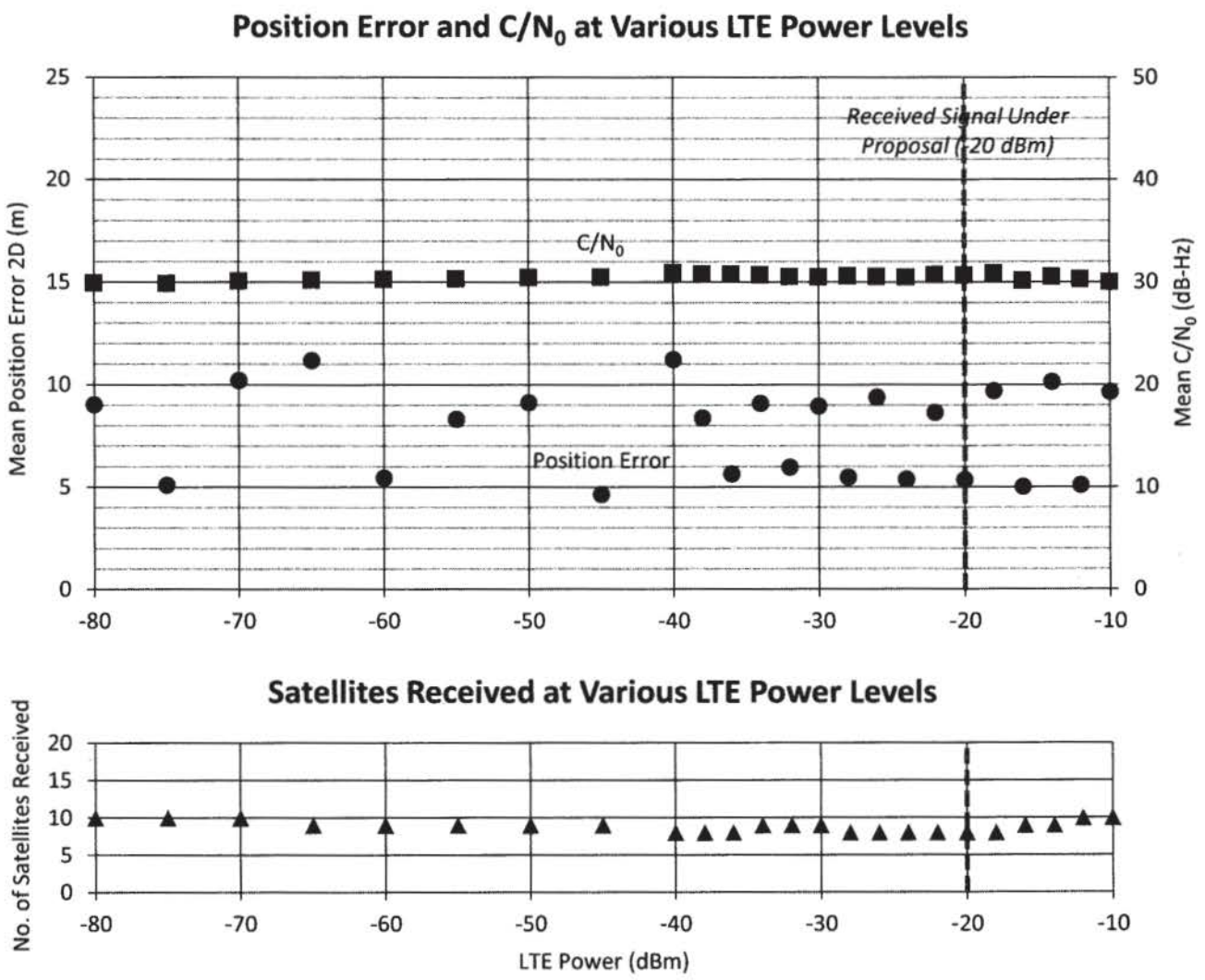
Samsung Tablet
Open Sky with Motion | 1526-1536 MHz LTE (Downlink)

Device Category: Cellular
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Samsung Tablet
Antenna: Internal

GPS Condition:
Open Sky with Motion

LTE Condition:
1526-1536 MHz LTE (Downlink)



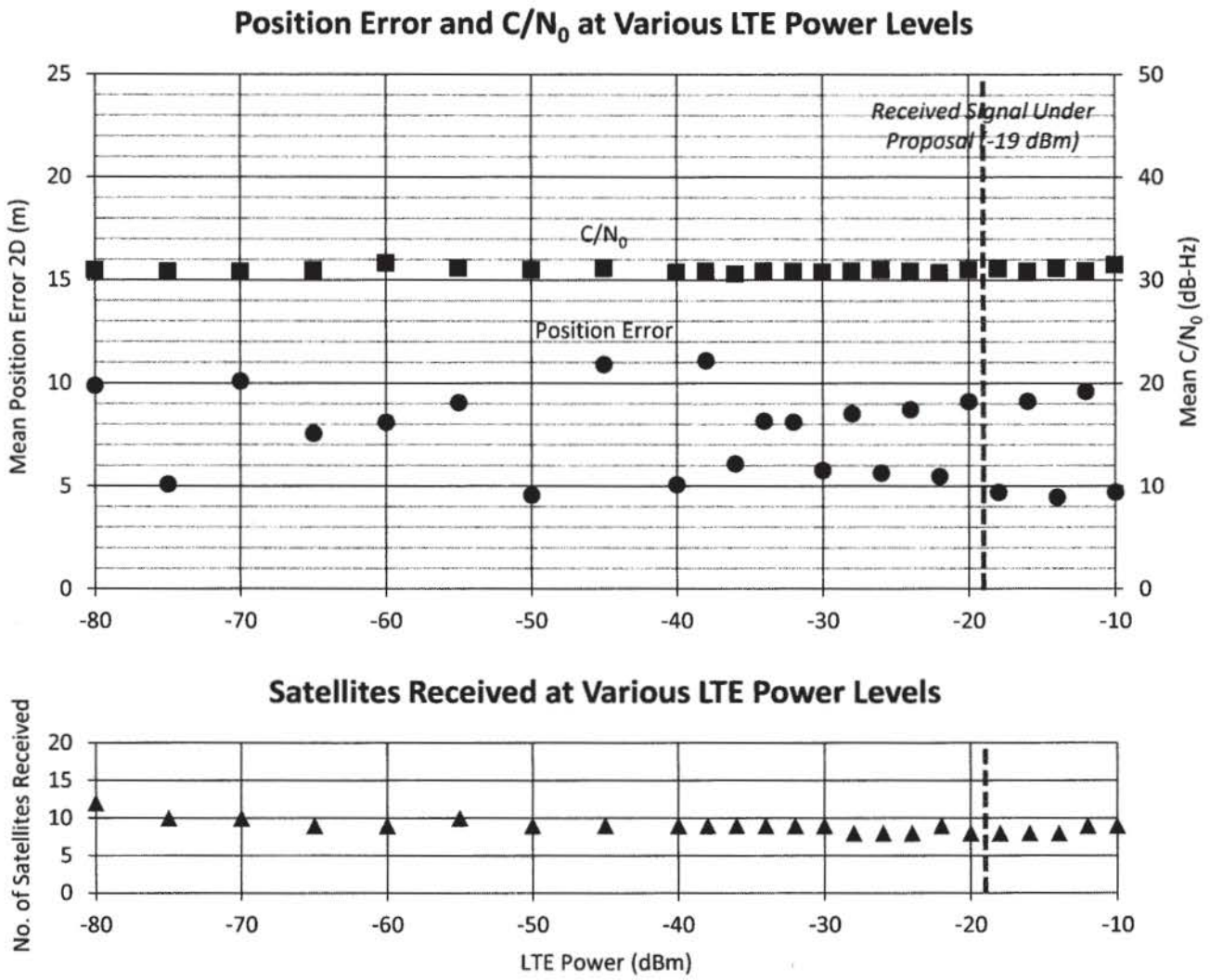
Samsung Tablet
Open Sky with Motion | 1627.5-1637.5 MHz LTE (Uplink)

Device Category: Cellular
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Samsung Tablet
Antenna: Internal

GPS Condition:
Open Sky with Motion

LTE Condition:
1627.5-1637.5 MHz LTE (Uplink)



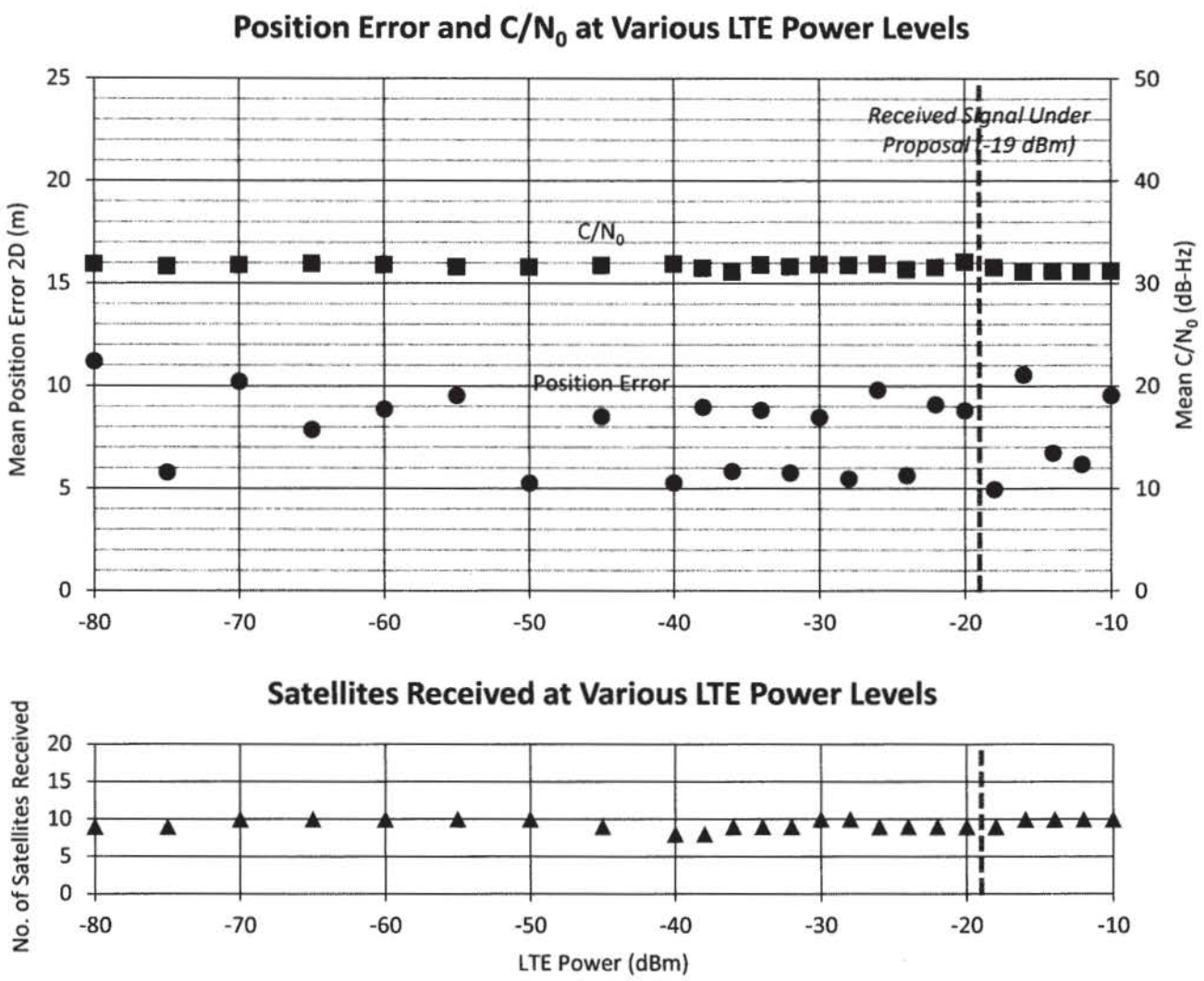
Samsung Tablet
Open Sky with Motion | 1646.5-1656.5 MHz LTE (Uplink)

Device Category: Cellular
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Samsung Tablet
Antenna: Internal

GPS Condition:
Open Sky with Motion

LTE Condition:
1646.5-1656.5 MHz LTE (Uplink)



● Mean Position Error 2D (m)

■ Mean C/No (dB-Hz)

▲ No. of Satellites Received

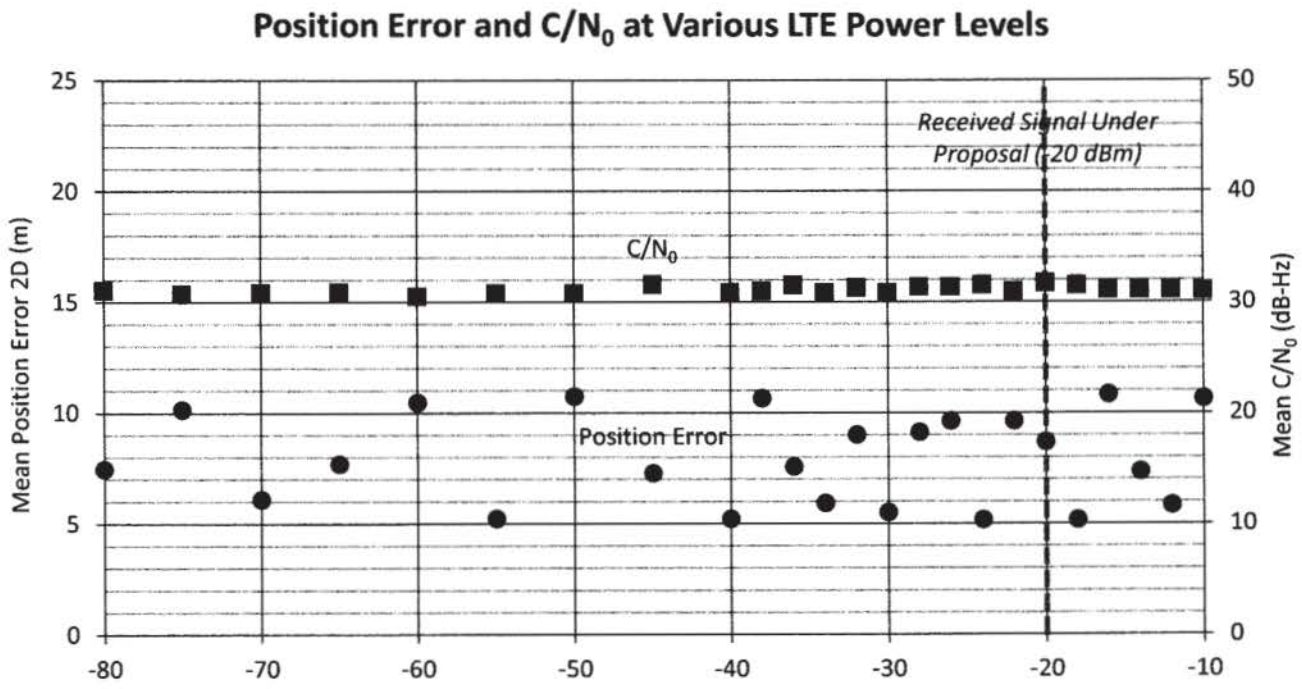
Samsung Tablet
Open Sky with Motion | 1670-1680 MHz LTE (Downlink)

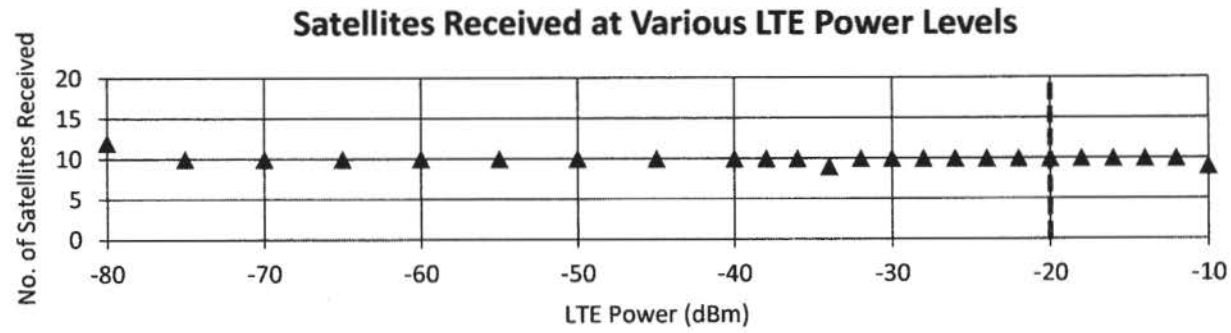
Device Category: Cellular
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Samsung Tablet
Antenna: Internal

GPS Condition:
Open Sky with Motion

LTE Condition:
1670-1680 MHz LTE (Downlink)





● Mean Position Error 2D (m)
■ Mean C/No (dB-Hz)
▲ No. of Satellites Received

Samsung Galaxy S5 and S6

Samsung Galaxy S5 and S6
Description of A-GPS Testing for Cellular Phones

- A-GPS (Assisted GPS) is a method of sending information to a mobile device from the network to improve GPS performance. Tests for A-GPS are defined in 3GPP (Third Generation Partnership Project).

- Samsung S5 and S6 were tested for A-GPS performance based on 3GPP standards.
  - Industry standard tests for cellphones/smartphones
  - Based on 2011 TWG cellphone testing

- Three tests were performed:
  - Accuracy of Location Provided for E911 Call
  - Dynamic Range: Ability to operate when large differences among GPS signal levels are present
  - Sensitivity: Ability to perform with low GPS signal levels

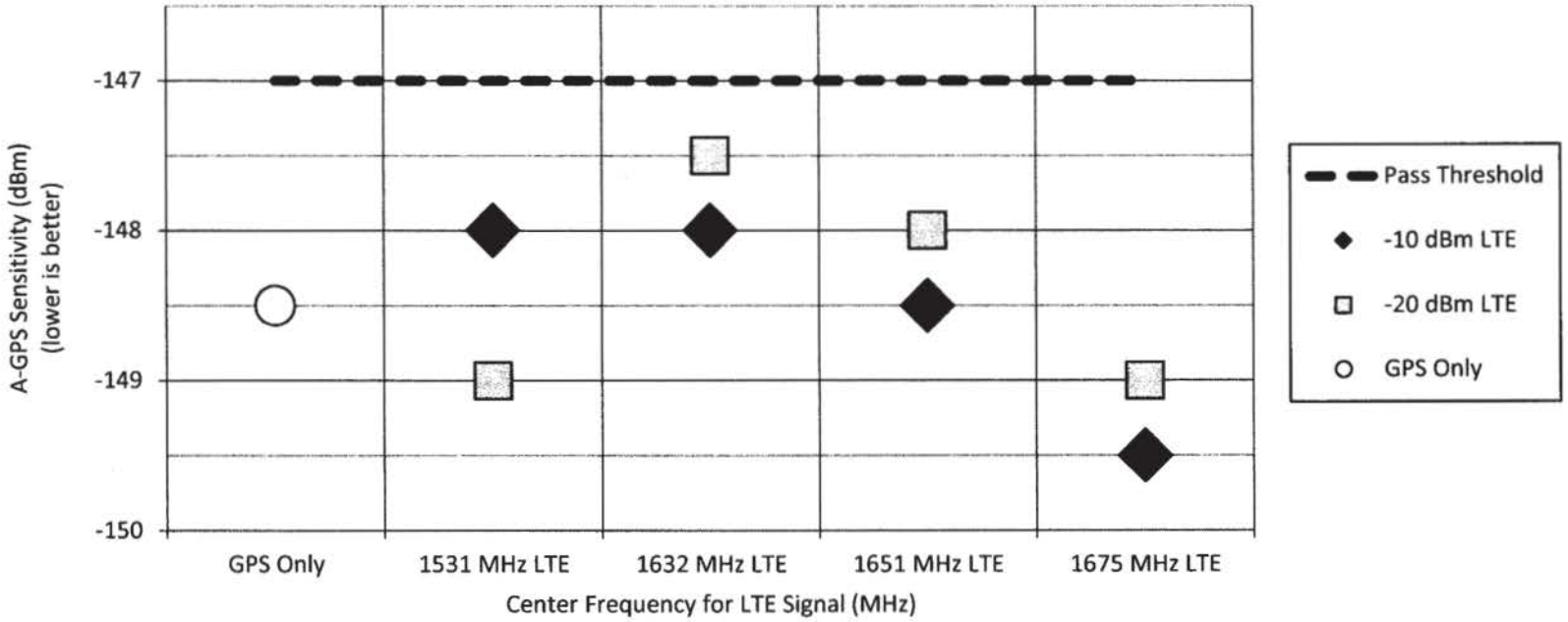
- LTE was added at -20 dBm for each of the four LTE frequencies (one at a time) for each of the 3 tests. Test was repeated at -10 dBm LTE.

- **Analysis**: Samsung S5 and S6 passed all tests at -20 dBm and -10 dBm LTE received

Samsung Galaxy S5 | A-GPS Test Results

LTE Power	Test	GPS Only	1526-1536 MHz	1627.5-1637.5 MHz	1646.5-1656.5 MHz	1670-1680 MHz
-20 dBm	Accuracy	Pass	Pass	Pass	Pass	Pass
-20 dBm	Dynamic Range	Pass	Pass	Pass	Pass	Pass
-20 dBm	Sensitivity	Pass	Pass	Pass	Pass	Pass
-10 dBm	Accuracy	Pass	Pass	Pass	Pass	Pass
-10 dBm	Dynamic Range	Pass	Pass	Pass	Pass	Pass
-10 dBm	Sensitivity	Pass	Pass	Pass	Pass	Pass

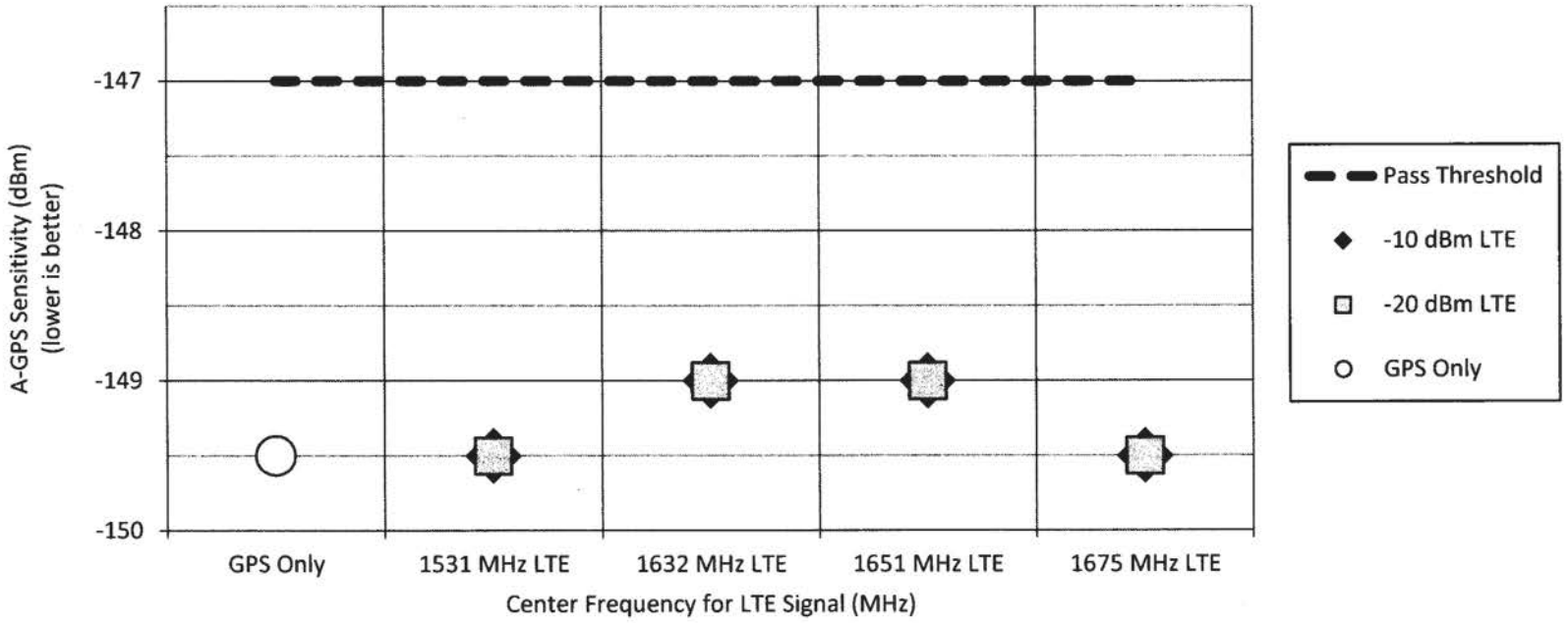
A-GPS Sensitivity of Samsung S5 with No LTE, -20 dBm LTE, and -10 dBm LTE Signals



Samsung Galaxy S6 | A-GPS Test Results

LTE Power	Test	GPS Only	1526-1536 MHz	1627.5-1637.5 MHz	1646.5-1656.5 MHz	1670-1680 MHz
-20 dBm	Accuracy	Pass	Pass	Pass	Pass	Pass
-20 dBm	Dynamic Range	Pass	Pass	Pass	Pass	Pass
-20 dBm	Sensitivity	Pass	Pass	Pass	Pass	Pass
-10 dBm	Accuracy	Pass	Pass	Pass	Pass	Pass
-10 dBm	Dynamic Range	Pass	Pass	Pass	Pass	Pass
-10 dBm	Sensitivity	Pass	Pass	Pass	Pass	Pass

A-GPS Sensitivity of Samsung S6 with No LTE, -20 dBm LTE, and -10 dBm LTE Signals



Appendix F:
Non-Certified Aviation Device

Non-Certified Aviation Device Condition: Open Sky

Test Performance under the Ligado GPS Proposal

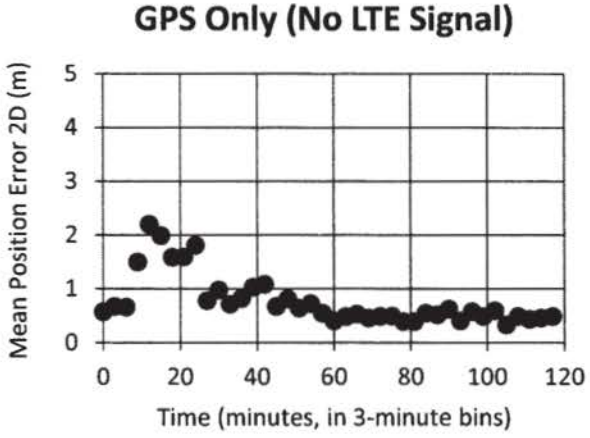
Device	Test	Antenna	1526-1536 MHz Downlink	1627.5-1637.5 MHz Uplink	1646.5-1656.5 MHz Uplink	1670-1680 MHz Downlink
Garmin GPSMAP 696	Open Sky	Internal	**No Impact**	**No Impact**	**No Impact**	**No Impact**

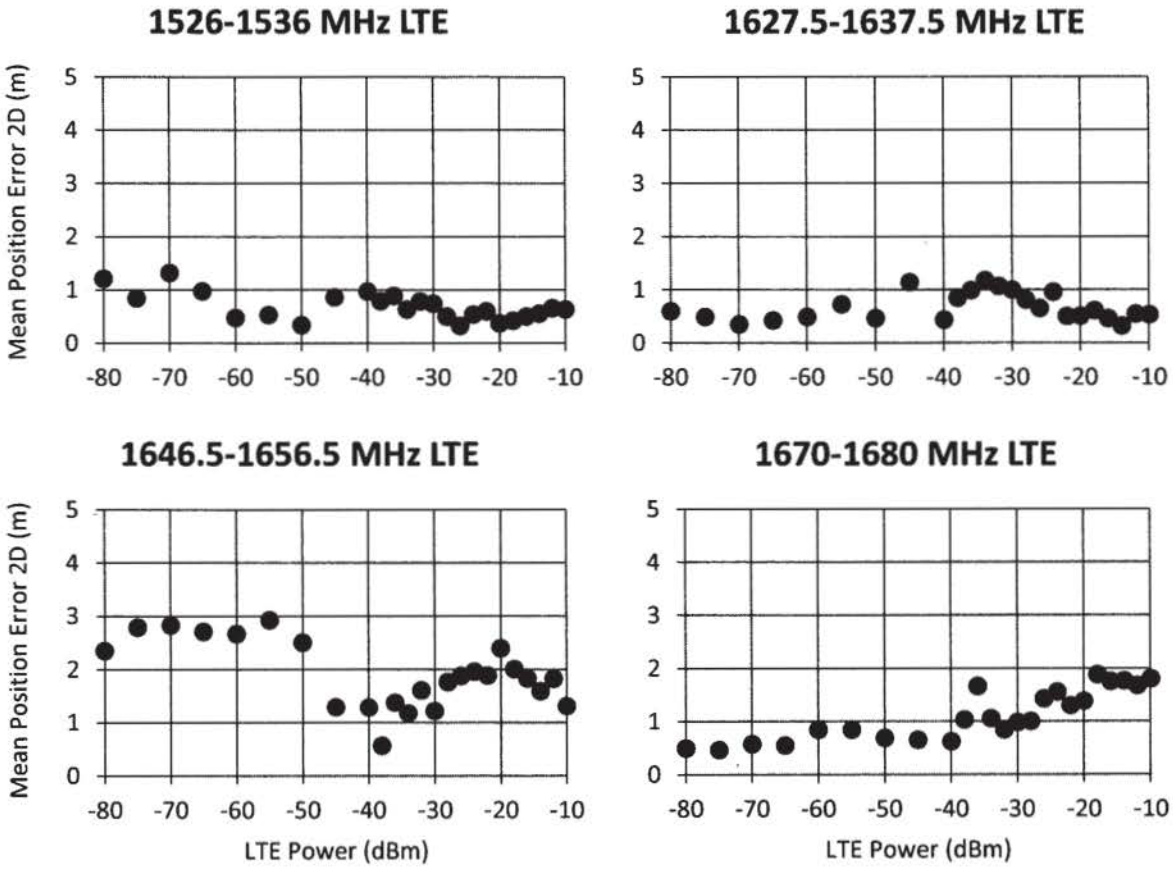
"No Impact" means that, with LTE received powers corresponding to the transmit power levels under the Ligado GPS proposal, there was no impact on the device performance compared to those KPI measurements with GPS alone.

Garmin GPSMAP 696

Condition: Open Sky

1526-1536 MHz Downlink	1627.5-1637.5 MHz Uplink	1646.5-1656.5 MHz Uplink	1670-1680 MHz Downlink
No Impact	No Impact	No Impact	No Impact





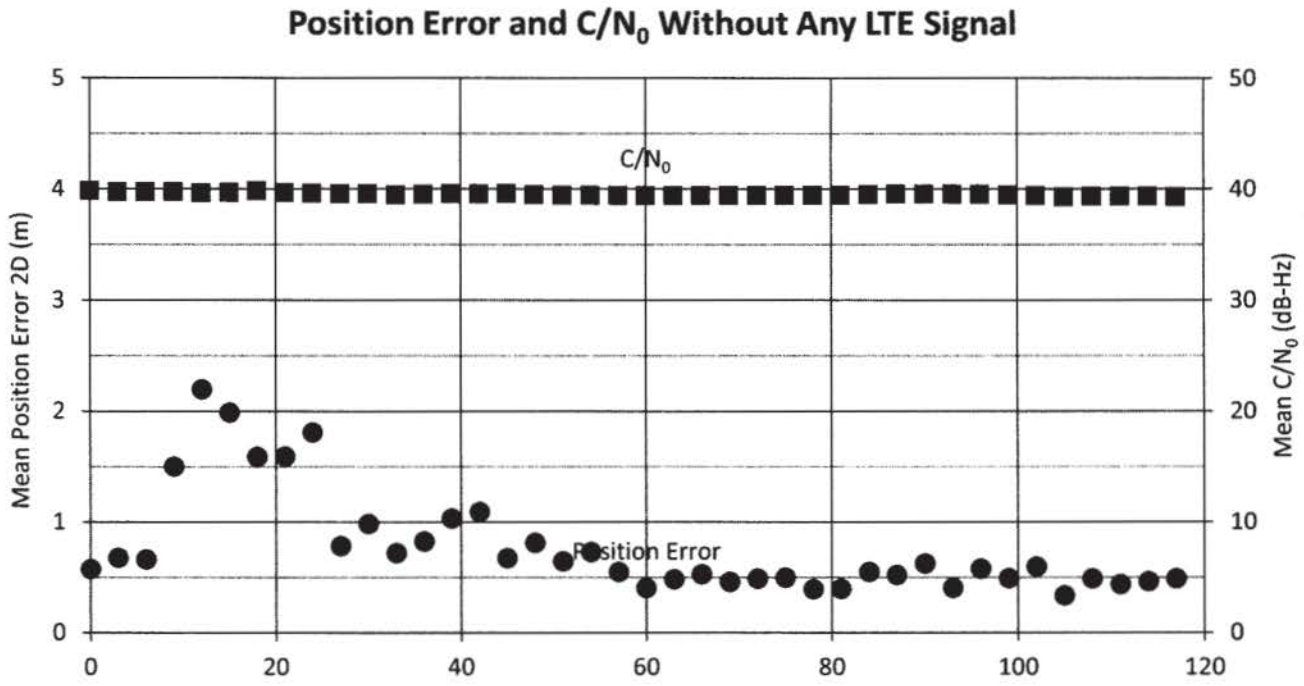
Garmin GPSMAP 696
Open Sky | GPS Only (No LTE Signal)

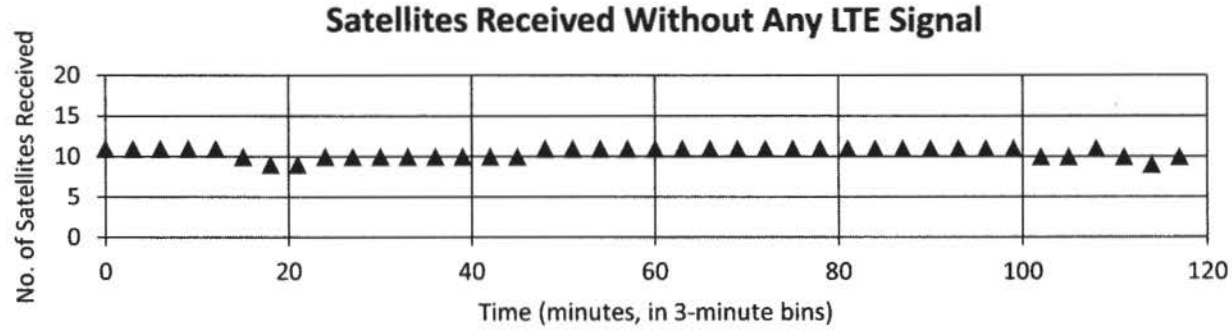
Device Category:
Non-Certified Aviation
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Garmin GPSMAP 696
Antenna: Internal

GPS Condition:
Open Sky

LTE Condition:
GPS Only (No LTE Signal)





● Mean Position Error 2D (m)
■ Mean C/No (dB-Hz)
▲ No. of Satellites Received

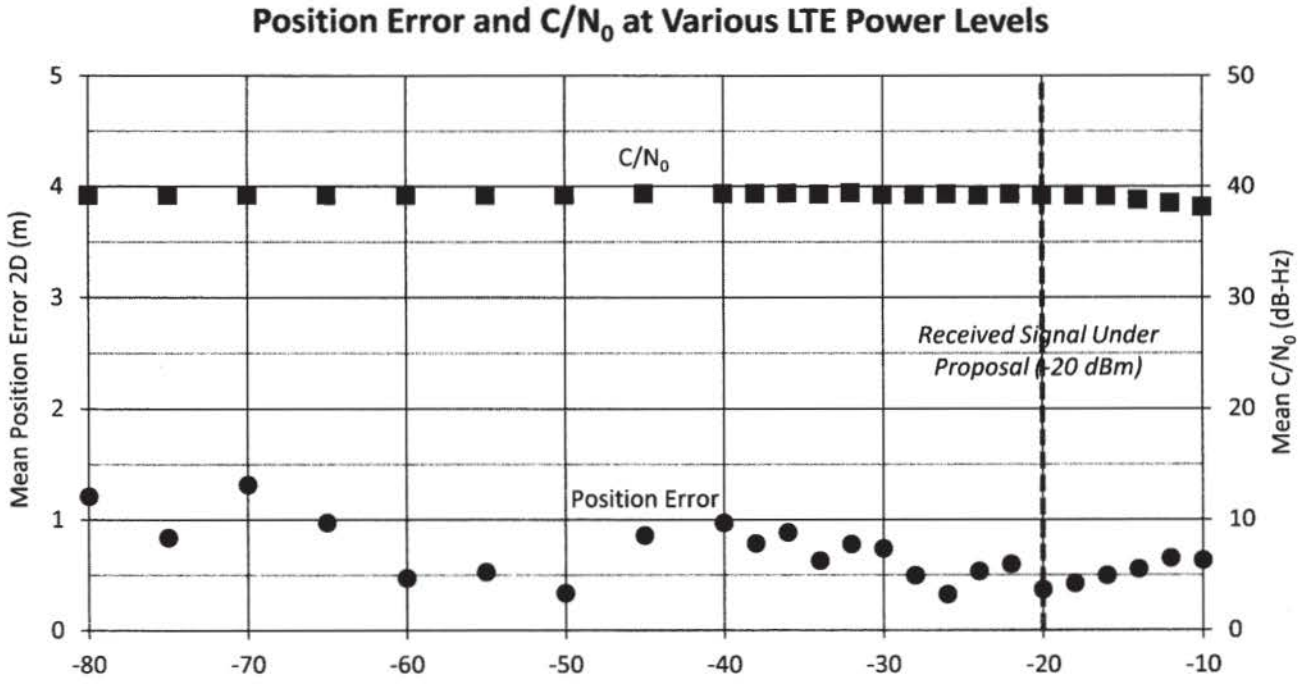
Garmin GPSMAP 696
Open Sky | 1526-1536 MHz LTE (Downlink)

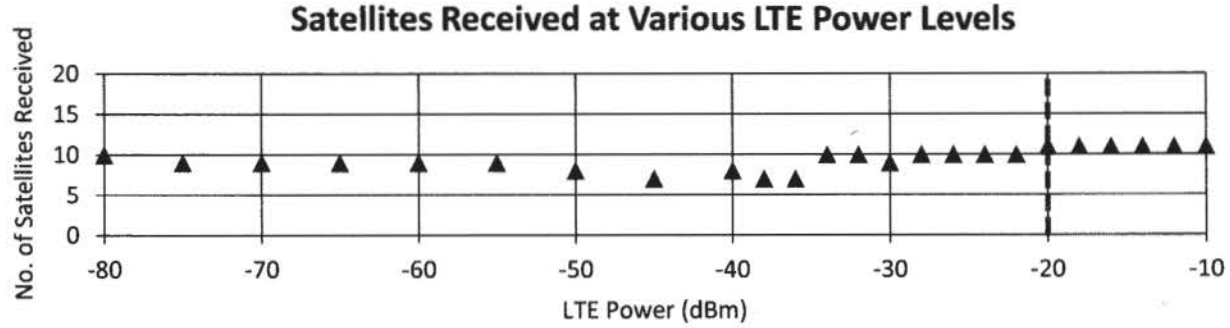
Device Category:
Non-Certified Aviation
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Garmin GPSMAP 696
Antenna: Internal

GPS Condition:
Open Sky

LTE Condition:
1526-1536 MHz LTE (Downlink)





● Mean Position Error 2D (m)
■ Mean C/No (dB-Hz)
▲ No. of Satellites Received

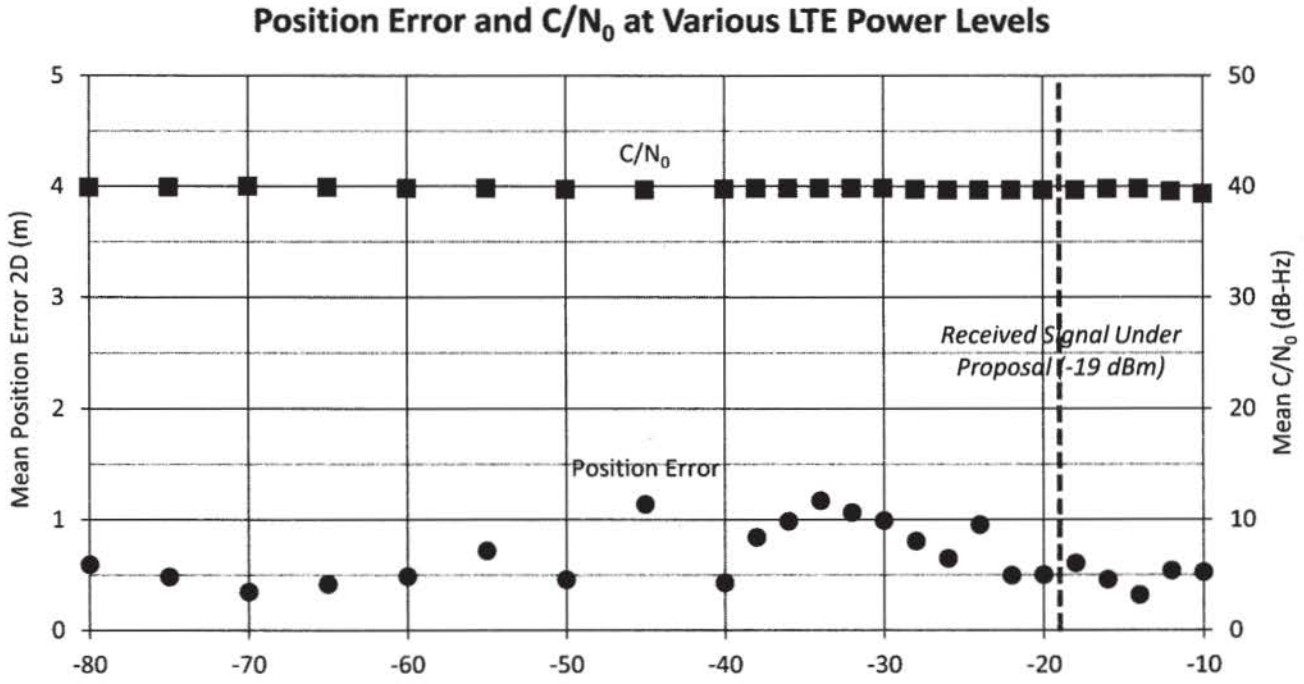
Garmin GPSMAP 696
Open Sky | 1627.5-1637.5 MHz LTE (Uplink)

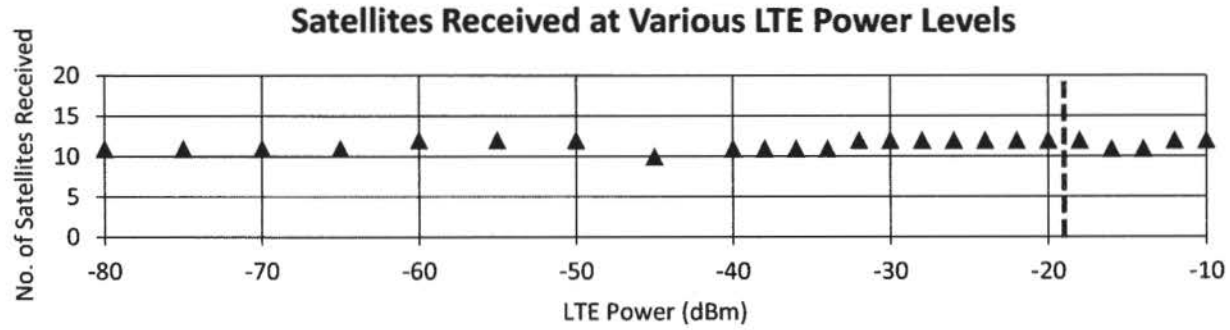
Device Category:
Non-Certified Aviation
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Garmin GPSMAP 696
Antenna: Internal

GPS Condition:
Open Sky

LTE Condition:
1627.5-1637.5 MHz LTE (Uplink)





● Mean Position Error 2D (m)
■ Mean C/No (dB-Hz)
▲ No. of Satellites Received

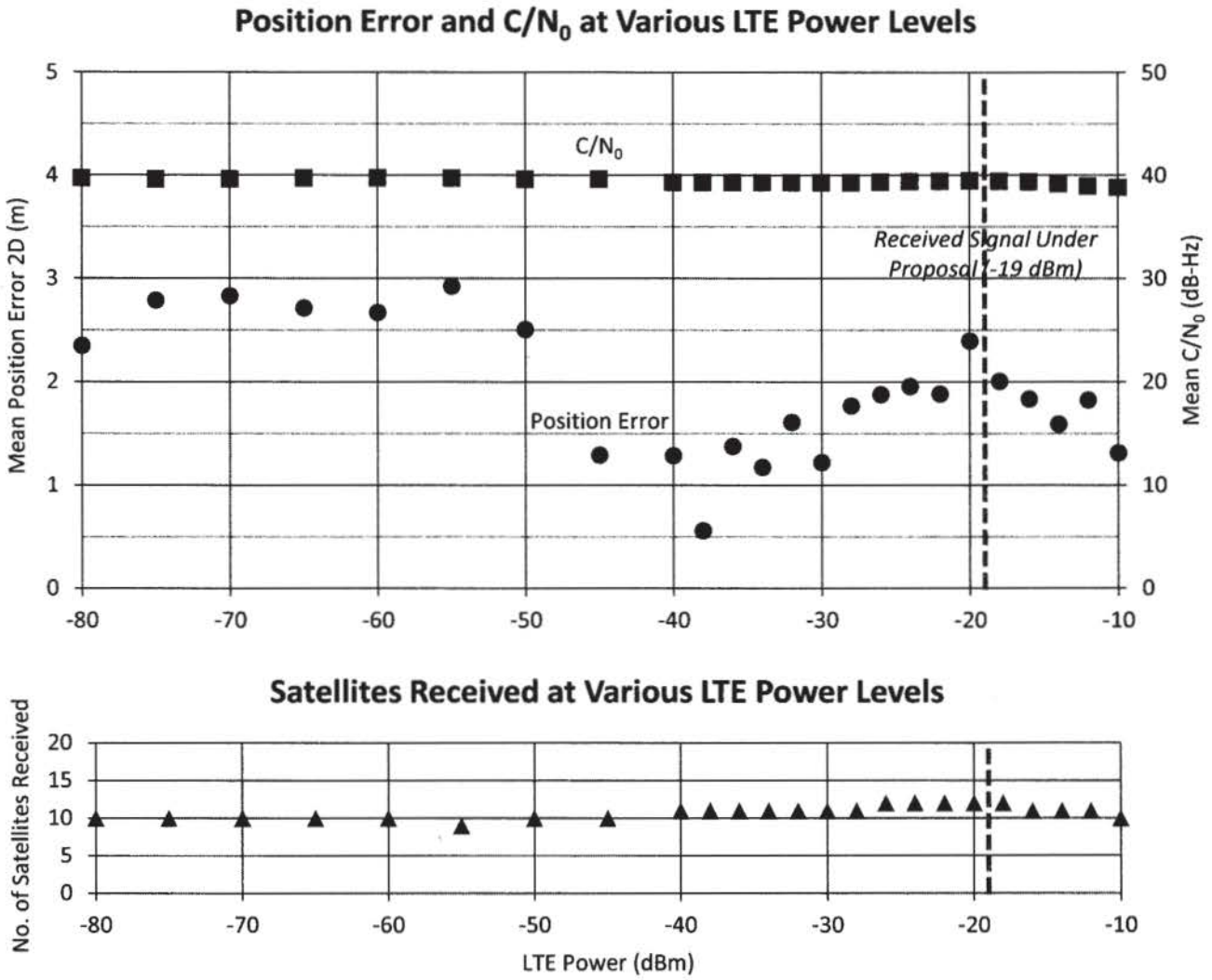
Garmin GPSMAP 696
Open Sky | 1646.5-1656.5 MHz LTE (Uplink)

Device Category:
Non-Certified Aviation
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Garmin GPSMAP 696
Antenna: Internal

GPS Condition:
Open Sky

LTE Condition:
1646.5-1656.5 MHz LTE (Uplink)



● Mean Position Error 2D (m)
■ Mean C/No (dB-Hz)
▲ No. of Satellites Received

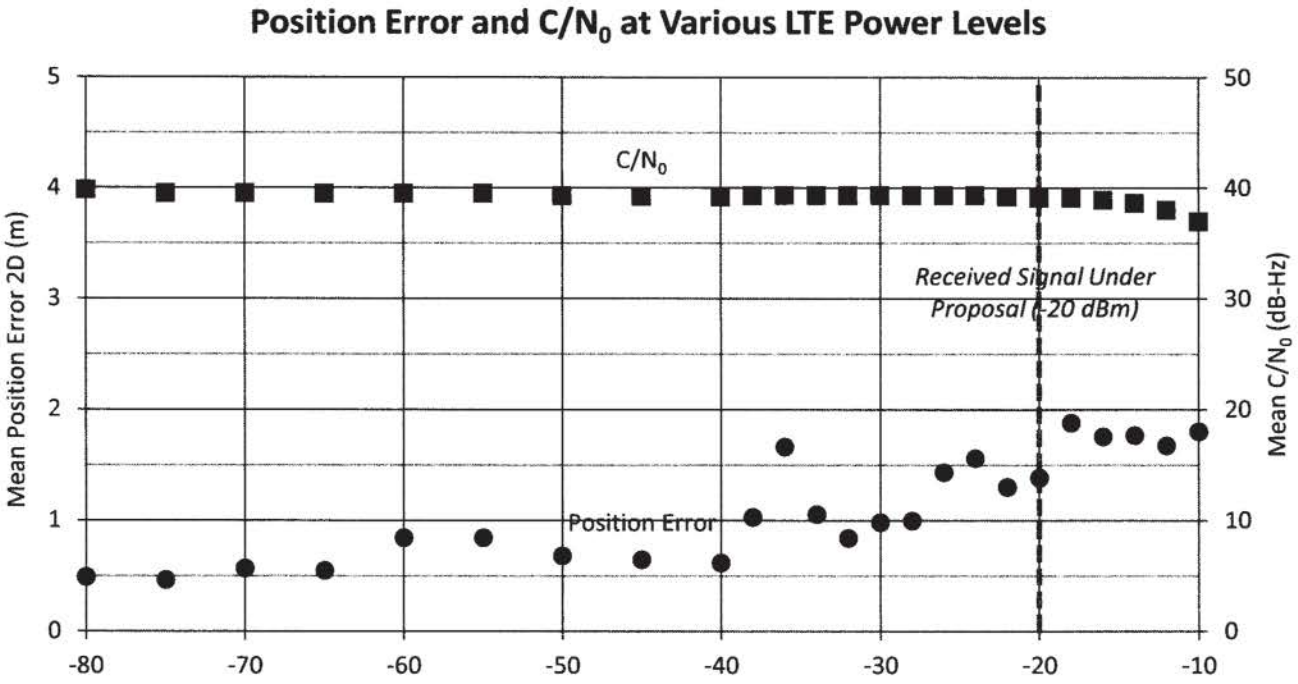
Garmin GPSMAP 696
Open Sky | 1670-1680 MHz LTE (Downlink)

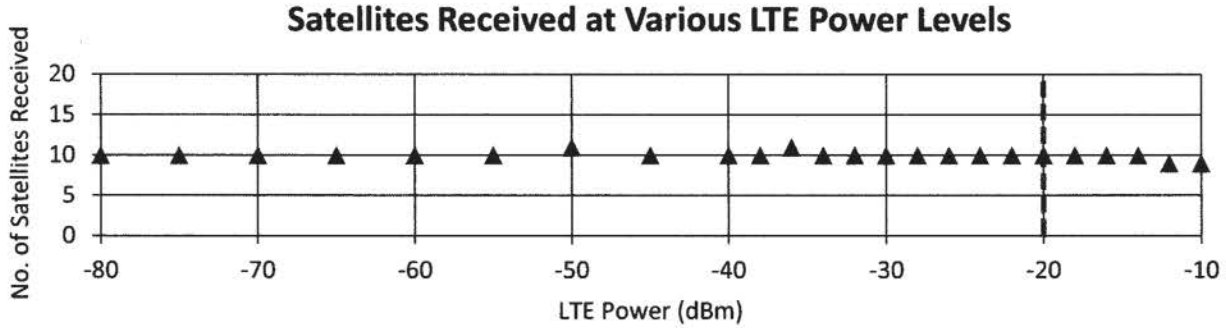
Device Category:
Non-Certified Aviation
Key Performance Indicator:
Mean Position Error 2D (m)
(3-minute averaging window)

Device: Garmin GPSMAP 696
Antenna: Internal

GPS Condition:
Open Sky

LTE Condition:
1670-1680 MHz LTE (Downlink)





● Mean Position Error 2D (m)
■ Mean C/No (dB-Hz)
▲ No. of Satellites Received

GPS Sensitivity Measurement Plan

May 9, 2016
v2

1 Measurement Plan Executive Summary

1.1 Purpose

The purpose of this GPS receiver measurement project is to collect data required for establishing the potential impacts on GPS Key Performance Indicators (KPIs) that a user may experience when adjacent band LTE downlink and uplink signals are present. In addition to KPI values, signal to noise ratios in the form of reported C/N_0 values will also be collected when possible, subject to the data interface supported on the device. Emphasis is on real world expected LTE signal levels.

1.2 Deliverables

For each device tested, the main deliverables are detailed records of the KPI statistics observed as a function of LTE signal levels at the input to the GPS device. A determination is made of the received power levels in adjacent bands versus observed changes in KPI statistics without any pass/fail determination.

2 KPI Measurement Plan

2.1 Key Performance Indicators (KPIs) for Cellular GPS Devices

Cellular GPS devices are tested using radiated signals as per the TWG devised test plans for Accuracy (TWG Report, Sections 3.2.9.2.2 and 3.2.9.2.3) and Sensitivity (TWG Report, Section 3.2.9.2.1). In addition, similarly devised GPS Dynamic Range tests will be performed. These 3GPP tests are found in 3GPP Specification TS 37.571-1 for UTRAN and E-UTRAN based systems. The Sensitivity test is described in section 7.1, the Accuracy test is described in section 7.2, and the Dynamic Range test is described in section 7.3 of 3GPP TS 37.571-1.

The three figures below are taken from TS 37-571-1; they summarize performance requirements and test conditions for the three KPIs described above.

Table 7.1.1.2: Requirements Sensitivity Coarse time assistance

Success rate	2-D position error	Max response time
95 %	100 m	20 s

Table 7.1.1.3: Parameters Sensitivity Coarse time assistance - Sub-Test 1

Parameters	Unit	Value
Number of generated satellites	-	8
HDOP Range	-	1.1 to 1.6
Propagation conditions	-	AWGN
GPS Coarse time assistance error range	seconds	±2
GPS L1 C/A Signal for one satellites	dBm	-142
GPS L1 C/A Signal for remaining satellites	dBm	-147

Figure 1 3GPP Sensitivity KPI and test conditions from TS 37.571-1

Table 7.2.2: Requirements Nominal Accuracy - Sub-Test 1

Success rate	2-D position error	Max response time
95 %	30 m	20 s

Table 7.2.4: Parameters Nominal Accuracy - Sub-Test 1

Parameters	Unit	Value
Number of generated satellites	-	8
HDOP Range	-	1.1 to 1.6
Propagation conditions	-	AWGN
GPS Coarse Time assistance error range	seconds	±2
GPS L1 C/A Signal for all satellites	dBm	-130

Figure 2 3GPP Accuracy KPI and test setup from TS 37.571-1

Table 7.3.2: Requirements Dynamic Range

Success rate	2-D position error	Max response time
95 %	100 m	20 s

Table 7.3.3: Parameters Dynamic Range - Sub-Test 1

Parameters	Unit	Value
Number of generated satellites	-	6
HDOP Range	-	1.4 to 2.1
GPS Coarse Time assistance error range	seconds	±2
Propagation conditions	-	AWGN
GPS L1 C/A Signal for 1st satellite	dBm	-129
GPS L1 C/A Signal for 2nd satellite	dBm	-135
GPS L1 C/A Signal for 3rd satellite	dBm	-141
GPS L1 C/A Signal for 4th satellite	dBm	-147
GPS L1 C/A Signal for 5th satellite	dBm	-147
GPS L1 C/A Signal for 6th satellite	dBm	-147

Figure 3 3GPP Dynamic Range from TS 37.571-1

2.2 Key Performance Indicators (KPIs) for GPS Devices

The table below provides a list of GPS KPIs for the different GPS device classes tested. C/N_0 and the number of satellites being tracked are reported by some of the devices tested in their output NMEA messages. When available, they are collected and included in the statistical analysis. Some High Precision and General Location and Navigation (GLN) devices provide an indication of RTK and/or WAAS lock. When available, they are also collected.

Table 1 KPIs for GPS device category

	Aviation (Uncert.)	High Precision	Cellular	GLN
KPI	• 2D Position Error	• 3D Position Error	• 3GPP KPIs • 2D Position Error	• 2D Position Error.
System Data	• Satellites in view • C/No	• Satellites in view • C/N_0 • Loss of RTK and/or WAAS lock	• Satellites in view • C/N_0	• Satellites in view • C/N_0 • WAAS lock